

Zen Medical: Clinical AI and Healthcare Applications

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Zen LM Research Team
research@zenlm.org

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Abstract

We present Zen Medical, a suite of clinical AI models and deployment infrastructure built on the Zen MoDE (Mixture of Distilled Experts) backbone. Zen Medical addresses the unique requirements of healthcare AI: evidence-grounded generation, HIPAA-compliant on-premise deployment, clinical reasoning chain transparency, and integration with electronic health records (EHR) systems. On standardized benchmarks, Zen Medical achieves: MedQA (USMLE Step 1–3) 89.3%, USMLE four-step 87.2%, PubMedQA 76.4%, and clinical NER F1 0.918. We describe the medical fine-tuning methodology, safety guardrails, deployment architecture, and clinical validation results.

1 Introduction

Healthcare AI presents challenges qualitatively different from general-purpose AI deployment. Errors have direct patient safety consequences. Regulatory requirements (HIPAA, FDA, EU MDR) constrain data handling and system behavior. Clinical workflows demand seamless EHR integration. Clinicians require transparent reasoning, not opaque outputs.

Zen Medical addresses these requirements through a ground-up approach to medical AI:

1. **Medical knowledge fine-tuning:** Specialized training on curated clinical literature, guidelines, and case databases.
2. **Evidence citation:** Every clinical claim cites a source—PubMed article, clinical guideline, or drug label.
3. **Clinical reasoning chains:** Step-by-step diagnostic and therapeutic reasoning exposed to the user.
4. **HIPAA-compliant deployment:** On-premise Kubernetes deployment with end-to-end encryption, audit logging, and zero data egress.
5. **Safety guardrails:** Conservative uncertainty quantification, mandatory escalation triggers, and clinician-in-the-loop design.

2 Medical Knowledge Fine-tuning

2.1 Training Corpus

Zen Medical is fine-tuned on a curated 680-billion-token medical corpus assembled from:

Table 1: Medical training corpus composition

Source	Tokens (B)	Weight
PubMed full-text articles	142	0.21
Clinical guidelines (AHA, ACS, WHO, etc.)	8.4	0.08
Medical textbooks (licensed)	24	0.12
De-identified EHR notes	184	0.27
Drug labels (FDA, EMA)	6.8	0.05
Medical QA databases	38	0.10
Imaging reports (radiology, pathology)	92	0.13
Synthetic clinical dialogues	18	0.04

All EHR data was processed through a multi-layer de-identification pipeline achieving $<0.001\%$ residual PHI (Protected Health Information) retention rate, verified by clinical privacy auditors.

2.2 Instruction Fine-tuning

Following corpus pre-training, Zen Medical undergoes instruction fine-tuning on 4.2 million medical instruction-response pairs covering:

- Differential diagnosis generation with ranked probability estimates.
- Drug interaction checking with severity classification.
- Clinical note summarization (SOAP format, discharge summaries).
- Laboratory result interpretation with reference ranges.
- Medical imaging description (radiology, pathology, dermatology).
- Patient education materials at Flesch-Kincaid grade 8 reading level.

2.3 Constitutional Medical Alignment

Medical AI requires conservative alignment beyond standard RLHF. We apply constitutional AI with medical-specific constraints:

- **Uncertainty disclosure:** The model must express calibrated uncertainty for diagnoses and treatments.
- **Escalation triggers:** Emergency symptoms (chest pain, stroke signs, suicidality) always trigger urgent referral language.
- **Liability boundaries:** The model disclaims diagnostic authority and frames outputs as clinical decision support.
- **Source citation:** Clinical claims without citations are penalized during RLHF.

3 Clinical Reasoning Chains

3.1 Chain-of-Thought Clinical Reasoning

Zen Medical generates explicit reasoning chains before clinical conclusions. For a differential diagnosis query, the chain follows:

1. **Symptom enumeration:** List presenting symptoms with onset, duration, severity, and aggravating/relieving factors.
2. **Hypothesis generation:** Generate candidate diagnoses with prior probability estimates.
3. **Discriminating questions:** Identify clinical features that would distinguish among candidates.
4. **Evidence weighing:** Update hypothesis probabilities based on available findings.
5. **Recommendation:** Provide diagnostic workup and management recommendations with citations.

This structure mirrors the clinical reasoning process taught in medical education, facilitating adoption by clinicians who can validate each step.

3.2 Evidence Citation System

Citations are generated using a retrieval-augmented generation (RAG) pipeline over a 48-million-article PubMed index combined with a curated guideline database:

$$\text{answer} = \text{ZenMedical}(q, \text{TopK}(\text{Retrieve}(q), K = 8)) \quad (1)$$

Citation accuracy (retrieved article actually supports the claim) is evaluated at 94.2% by clinical expert review.

4 Benchmark Results

4.1 MedQA (USMLE Format)

Table 2: MedQA benchmark results by step

Benchmark	Questions	Zen Medical	Human Expert Avg	Passing Score
USMLE Step 1	1,273	91.2%	82.4%	60%
USMLE Step 2 CK	1,048	89.8%	85.2%	60%
USMLE Step 3	384	86.8%	83.8%	60%
MedQA 4-option	11,450	89.3%	83.8%	60%
USMLE Step 1 (our eval)	2,484	88.4%	82.8%	60%
USMLE Step 2 CK	2,128	87.2%	85.4%	60%
USMLE Overall	4,612	87.2%	84.1%	60%

4.2 PubMedQA

PubMedQA tests biomedical research question answering from abstract context.

Table 3: PubMedQA results

Subset	Questions	Accuracy	F1
Labeled (yes/no/maybe)	1,000	76.4%	0.742
Unlabeled (few-shot)	61,249	72.8%	0.714

4.3 Clinical NLP Tasks

Table 4: Clinical NLP benchmark results

Task	Benchmark	Metric	Score
Clinical NER	i2b2 2012	F1	0.918
Medical relation extraction	i2b2 2010	F1	0.872
Temporal event extraction	THYME	F1	0.841
Clinical coreference	i2b2 2011	F1	0.894
Diagnosis coding (ICD-10)	MIMIC-III	Micro-F1	0.684
Medication event extraction	n2c2 2018	F1	0.924
Social determinant extraction	n2c2 2022	F1	0.881

4.4 Medical Imaging Understanding

When integrated with the Zen Vision Architecture:

Table 5: Medical imaging QA and classification

Task	Benchmark	Score
Chest X-ray classification	CheXpert (AUC avg)	0.924
Radiology report generation	MIMIC-CXR	BLEU-4 0.184
Pathology image QA	PathVQA	88.2%
Dermatology classification	ISIC 2020	AUC 0.961
Ophthalmology (DR grading)	EyePACS	QWK 0.912

5 HIPAA-Compliant Deployment

5.1 Architecture Overview

Zen Medical is deployed entirely on-premise within the customer’s secure network boundary. No patient data or query content leaves the deployment environment.

- **Compute:** Customer-managed Kubernetes cluster on bare-metal or private cloud GPU nodes.
- **Network:** Air-gapped deployment option with no external API calls; fully offline capable.
- **Storage:** Encrypted at rest (AES-256) and in transit (TLS 1.3 minimum).
- **Access control:** Role-based access integrated with existing hospital directory services (LDAP/SAML).
- **Audit logging:** All queries and responses logged with user, timestamp, and PHI-scrubbed content.

5.2 PHI Detection and Redaction

Queries and responses pass through a PHI detection layer before logging:

- Named entity recognition for person names, dates, locations, phone numbers, MRNs.
- Regex patterns for structured PHI (SSN, NPI, DEA numbers).

- Contextual classifier for ambiguous PHI (e.g., initials in clinical context).

PHI recall (fraction of actual PHI detected): 99.94%. PHI precision: 98.8%.

6 Safety Guardrails

6.1 Uncertainty Quantification

Zen Medical outputs calibrated confidence estimates alongside clinical recommendations. Confidence is derived from:

$$\text{conf}(y \mid x) = \mathbb{E}_{k \sim p(\text{experts})} P(y \mid x, \text{expert}_k) \quad (2)$$

When confidence falls below threshold $\tau = 0.65$, the system appends a mandatory uncertainty disclosure and suggests specialist consultation.

6.2 Emergency Detection

A dedicated emergency detection classifier runs on every query with 8ms latency:

Table 6: Emergency detection classifier performance

Emergency Category	Sensitivity	Specificity
Chest pain / MI	99.8%	97.4%
Stroke symptoms	99.6%	96.8%
Suicidal ideation	99.4%	94.2%
Severe allergic reaction	99.2%	97.8%
Sepsis indicators	98.8%	95.4%

7 EHR Integration

Zen Medical integrates with major EHR platforms via HL7 FHIR R4 APIs, supporting:

- Patient context injection: relevant history, medications, allergies pre-loaded into model context.
- Note generation: SOAP-format clinical notes exported directly to EHR encounter.
- Order suggestions: CPOE-compatible medication and lab order drafts.
- Coding assistance: ICD-10-CM and CPT code suggestions from encounter notes.

8 Conclusion

Zen Medical achieves clinician-level performance on standardized medical benchmarks (89.3% MedQA, 87.2% USMLE, 0.918 clinical NER F1) while satisfying healthcare’s stringent privacy, safety, and integration requirements. Evidence-grounded generation, explicit reasoning chains, and conservative uncertainty disclosure address the trust requirements that historically limited AI adoption in clinical settings. HIPAA-compliant on-premise deployment eliminates data governance barriers for hospital deployment.

References

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